

## DATA MANAGEMENT WORKING GROUP REPORT

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(Note: This is a summary of the oral presentation by Dave Smith of JPL)

The first slide (Fig 1) represents the membership of our working group. You can see the diversity of people from the industry and government segments. Ed Filardo was the Chairman and Dave Smith was the Co-Chairman.

The next slide (Fig 2) represents a summary of requirements for some missions in terms of both the I/O data rate in MBPS and the processor speed in MOPS (Mega-operations per sec). This chart will give you some idea of the range in fundamental computational requirements. For example, in the case of Galileo, we are talking about maybe a rather definite kick range of 1/2 MOPS and an I/O rate of about 1 Megabit per sec. As you move out to some of the more complex missions, as in the case of planetary missions like the Mars Rover, this requirement point moves out on the log scale until you get to about 5 MOPS for the processing with a comparable I/O rate level. And then as you go on out to some of the G & C (guidance and control) levels, the problems of Mars Rover move out at processor speed. Way at the top of the chart are some instrument requirements relating to EOS, where there is some data formatting that requires movement of data at around 200 MBPS or more. To try to process that data on board and get the data rate down from 500 to 600 Megabits, this kind of compression will require about 100 MOPS processing level. So to do data compression at this kind of rate, you try to have some sort of data handling on board the spacecraft in terms of a fiberoptic network or some other technology to handle the large I/O rate.

If you try to form a consensus of the needed processing rate requirements versus I/O rate it turns out you are kind of in a dead box, eliminating very far out things like on-board synthetic aperture radar processing. So you can see that we really need data storage devices that will handle up to a terabit. For Spacecraft 2000 we need data I/O fiberoptics networks that will handle rates of 200, 300, or 500 Megabits per sec and processors at least up to 10 Mops.

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There is a kind of gap in trying to get the processing speed, and NASA has been dependent on VHSIC technology, which is driven toward some of the military applications and not necessarily toward space. Also, this technology has some problems in terms of being single-hit upset sensitive and can not be used in space right now, although programs are in place to solve this and provide qualified VHSIC. NASA, and Harry Benz of Langley in particular, is trying to direct that program to solve some of our problems, but it should be noted that VHSIC has a ways to go.

The next chart (Fig 3) is a comment on improvement in flight qualified components and families for computing. Several of our group feel that instead of the 1750 instruction set or maybe a general purpose computer to do symbolics as well as numeric calculations, the instruction set for the commercial size is preferable. In order to get there, i.e. use commercial kinds of derivatives of processors and so forth, we have to flight qualify at least the components. One of the problems we have is that there is about six to ten years from getting a flight qualified processor or parts from where the technology has been inserted. So we need to develop some component technology which is fast, insensitive to total dose of radiation, and single hit upset insensitive. We feel there are a couple of approaches.

Sandia is building the 32000 chip set and the National 32000 chip set with their rad-hard process. That set should be available in the late 1990's, at least the 32 bit processor; and that could be switched to GaAs rather than the current CMOS. The expected result, if we stay with this program, is that you could get the 5 MIPS machine and components of a processor with feature sizes drawn again from the VHSIC program down to about 1 micron. We also need high density RAMS along that same vein too, with 4K RAMS the only thing available now; we need also to bring off some high speed CMOS logic family in terms of completing the electronics problem. So this is a base only; you don't have to do it with 32000 chips and we might equally put money into other schemes to get a processor in the 5-10 MIPS range.

For data storage (Fig 4), we said that at least a terabit capability is needed. The spacecraft requires this and in addition, support rates from 10 Megabits to a Gigabit level. For planetary missions, the magnetic tape technology development program or a derivative thereof will probably suffice to achieve lower power and weight. The optical disk storage technology needs to be brought along and flight qualified for improvement in speed and I/O buffering, however. We should have that kind of technology, terabit storage and rapid access by the year 2000.

Now, as we move ahead to Spacecraft 2000 and the desired 10 MIPS processor speed level, you get into parallel processing technology and the need for distributed operating systems that can manage fault tolerance (see Fig 6). These systems must have selective fault tolerant modes and be capable of doing high speed critical calculations. The development of such flexible operating systems would be a big payoff for Spacecraft 2000.

The next chart (Fig 5) concerns software development tools, which all of us agree is going to be a real necessity to keep the cost down for Spacecraft 2000. Software is coming to dominate our lives and especially those tools required for generating software requirements, design code, test procedures, and documentation. There is the question of software life cycle and software maintenance as the total number of lines goes up. We need a specific identification of these tools and their requirements. As the spacecrafts evolve from, perhaps a common to a more generic type you need to be able to change the associated software and update it with specific tools. We are dependent right now on space station and SDI for developing a lot of these tools and it will be necessary to find some way of transferring or adapting these tools to other planetary programs and earth-orbiting programs.

Now consider the slide on languages (Fig 7). The Space Station picked the ADA language. We looked at ADA and there are some shortcomings with this language. However, we think for Spacecraft 2000, ADA is still a good choice. We think some work needs to be done on compiler efficiency. ADA is not a really good real time language and has to be augmented with other special routines. There are some problems with interprocess communications. If you have to use ADA as a distributive processor, you may have to put these into the operating system rather than augment the language; this is a trade we will have to make. The objective is to get a higher order of language which would solve these problems and there is a need to study ADA extension versus standardizing on some other language. What those extensions are, will be very important to not only Space Station but to Spacecraft 2000.

The next slide (Fig 8) concerns fault tolerance and testing. Fault tolerance in the past had come from triplicating and voting with some watchdog timers and older concepts. We need to rethink these, especially in light of the new distributive processing systems. So SDI has brought this to focus and will depend on that to look at fault tolerance in a new light in terms of new ideas and architectures. Fault tolerant concepts need to be able to treat flexible connectivity of distributive machines and especially for distributive control.

What does that mean to fault tolerance now, with distributive control? You have to treat such things as Byzantine failures (someone is lying on the voting). When you get down to very fault tolerant systems, those kinds of improbable or low probability occurrences actually now become significant. SDI is putting a lot of money and resources into this arena and we want to try and ride their coat tails as much as possible.

The next chart is on fiberoptics networks (Fig 9). There are good programs on this subject at both Langley and Goddard. Research is being done at 300-500 Megabits in fiber optic networks. What needs to be done in addition to continuation of these programs is the work to continue to flight qualify the components and the protocols that go along with these systems. In particular, there

are different kinds of electronic components that go along with that kind of network that have to be flight qualified. I have listed some of the components here, and again note we are trying to do from 300-500 MBPS low error rate FOLANS, which is the fiberoptic land network in spacecraft.

Figures 10a and 10b are on the subject of communications protocol. At these rates you need real time dedicated response, reliable communications, and of course, we are talking very high band width. These are some of the characteristics of that network and without any one of those it is prohibitive, but you need a simultaneous constraint solution to solve all problems. The current link protocols can not handle the 100-300 Megabit band rate in software, and it's too complex for hardware; so new protocols are needed and work should be done to bring that along. It should be noted that this is a fairly open area at this point.

We are concerned about security (Fig 11), and that has to be looked at right now as we are talking about the operating system. And we are also talking about embodying some security concepts into the early development stages for new protocols for the fiberoptics networks as it is very difficult to do it at a later stage of development. NASA's needs in this area should be carefully identified.

Finally, the last chart (Fig 12) is on technology evolvability. When you are trying to integrate high speed fiberoptics, processors, protocols, etc. you are going to need some sort of systems modeling. Every one of us agreed that we are lacking the systems tools to model such things as error rates and systems performance. These systems models are needed to look at the benefits and trades associated with technology evolution. If you want to replace your computer from the 16 bit to the 32 bit and move as the industry moves, you are going to have to design it to be transparent. That kind of system modeling is lacking. NASA needs a very firm planning program now to select and develop these tools. Whether there is funding from SDI or some other source, it needs to be a consistent plan put together by NASA.

#### DATA MANAGEMENT

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Figure 1.

## SPACE COMPUTATIONAL REQUIREMENTS SUMMARY

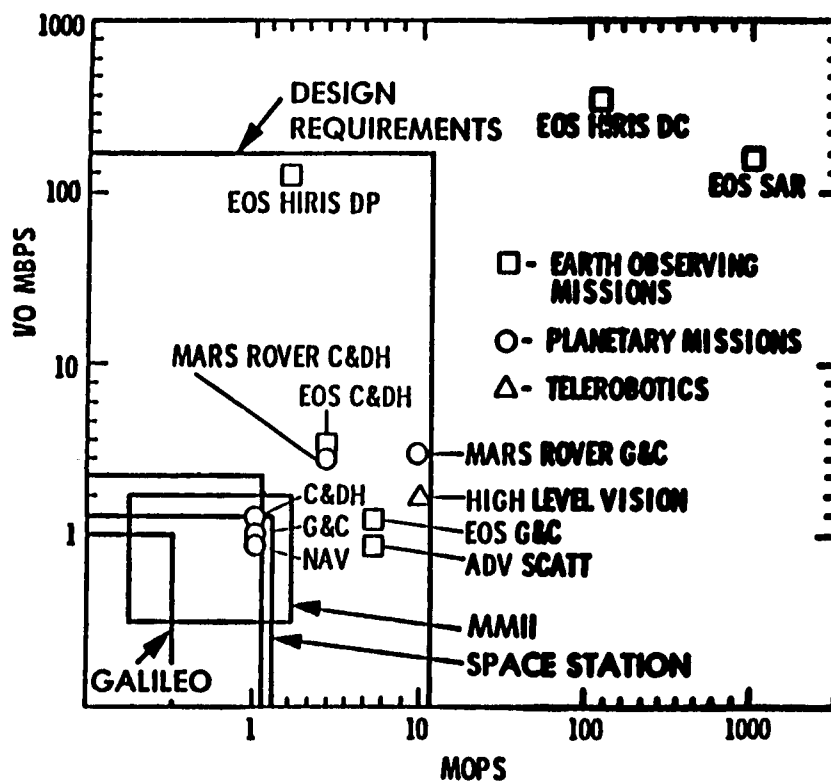
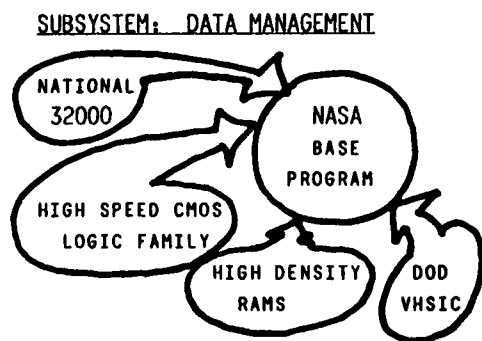


Figure 2.

### DATA MANAGEMENT -- FLIGHT QUALIFIED COMPONENTS & COMPUTERS



**SUBSYSTEM:** DATA MANAGEMENT

**PROBLEM:** CURRENT FLIGHT QUALIFICATION PROGRAM LAGS TECHNOLOGY INSERTION BY 6 TO 10 YEARS.

**OBJECTIVE:** DEVELOP FAST COMPONENT TECHNOLOGY WHICH IS RADIATION & SEU INSENSITIVE AND FLIGHT QUALIFIED BY LATE 1990'S. REESTABLISH COMPONENT BASE PROGRAM TO FILL GAP.

**APPROACH:** CONTINUE TO FUND SANDIA FOR PRODUCTION OF 32000 NATIONAL PART SET. ADD ADDITIONAL HC PARTS. ADD ADDITIONAL FUNDS TO ESTABLISH FEASIBILITY TO TRANSITION FROM CMOS TO  $G_A S$  OR OTHER IN LATE 1990'S.

**EXPECTED RESULTS:** FAST PROCESSOR PART SET WHICH WILL PROVIDE COMPUTER BUILDING BLOCKS FOR SPACECRAFT 2000. REDUCED FEATURE SIZE AT  $1 \frac{1}{4}$  MICRONS (FROM VHSIC THRUST) PLUS  $G_A S$  OR OTHER SHOULD PROVIDE 5 MIP MICROPROCESSOR, RAD HARD TO  $\gg 30,000$  RADS ( $S_I$ ) AND LET'S OF  $37 K_R$ .

Figure 3.

#### DATA MANAGEMENT -- DATA STORAGE

**PROBLEM:** s/c 2000 REQUIRES  $> 10^{12}$  BITS STORAGE AND RAPID ACCESS DATA BUFFERING; DEVICE SHOULD SUPPORT RATES FROM 10 MBPS TO 1 GBPS.

**OBJECTIVE:** DEVELOP LOW-POWER, WEIGHT MAGNETIC TAPE TECHNOLOGY FOR TERABIT RECORDER. BRING OPTICAL DISK DEVICE TECHNOLOGY ALONG FOR HIGH-SPEED BUFFER.

**APPROACH:** DEPEND ON CURRENT PROGRAM AT ODETICS FOR TAPE RECORDERS. AUGMENT TO REDUCE POWER AND WEIGHT. CONTINUE RCA SUPPORT TO OPTICAL DISK DEVICES: LOOK AT FLIGHT QUALIFICATION ISSUES.

**EXPECTATIONS:** SHOULD HAVE FLIGHT QUALIFIED STORAGE DEVICES FOR s/c 2000 WHICH CAN SUPPORT TERABIT STORAGE AND HIGH RATE BUFFERING.

Figure 4.

#### DATA MANAGEMENT -- SOFTWARE DEVELOPMENT TOOLS

**PROBLEM:** SPACECRAFT FLIGHT PROGRAMS IN THE YEAR 2000 WILL BE PROHIBITIVELY EXPENSIVE TO ENGINEER, DEVELOP, TEST AND MAINTAIN WITH THE SOFTWARE DEVELOPMENT TOOLS CURRENTLY IN USE.

**OBJECTIVE:** DEVELOP AN INTEGRATED SOFTWARE ENGINEERING AND DEVELOPMENT ENVIRONMENT ASSISTED BY EXPERT SYSTEM TECHNOLOGY FOR AIDING IN THE:

- 0 GENERATION OF SOFTWARE REQUIREMENTS, DESIGN, CODE, TEST CASES, TEST PROCEDURES AND DOCUMENTATION.
- 0 CONFIGURATION MANAGEMENT OF THE SOFTWARE.
- 0 IDENTIFICATION OF DESIGN, CODE, TEST CASE AND DOCUMENTATION CHANGES DICTATED BY REQUIREMENTS CHANGES.
- 0 LEARNING THE SOFTWARE SYSTEM (INTERACTIVE, USER-FRIENDLY ELECTRONIC "USER'S MANUAL").

**APPROACH:** 1. MONITOR THE DEVELOPMENT OF SUCH TOOLS BY SPACE STATION, SDI AND INDEPENDENT INDUSTRY INITIATIVES.

2. INITIATE NASA PROGRAMS FOR DEVELOPING SUCH TOOLS IF OTHER AGENCIES DO NOT.

**EXPECTED RESULTS:**

REDUCE SOFTWARE DEVELOPMENT AND MAINTENANCE COSTS BY AN ORDER OF MAGNITUDE.

D. BRADY

Figure 5.

## DATA MANAGEMENT -- OPERATING SYSTEMS

PROBLEM: THE NEED EXISTS FOR A DISTRIBUTED OPERATING SYSTEM WHICH HELPS MANAGE SYSTEM FAULT TOLERANCE AND WHICH CAN ITSELF SWITCH IN AND OUT OF HIGHLY FAULT TOLERANT CONFIGURATIONS AS A FUNCTION OF SOME SOFTWARE OR SYSTEM CONDITION.

OBJECTIVE: DEVELOP AN OPERATING SYSTEM PORTABLE TO THE ON-BOARD COMPUTERS OF THE YEAR 2000 WHICH PROVIDES THE FACILITIES FOR

- O RELIABLE INTERPROCESSOR COMMUNICATION
- O SYNCHRONIZATION OF COMMUNICATING TASKS BOTH ON THE LOCAL PROCESSOR AND ON OTHER PROCESSORS IN THE SYSTEM
- O SYSTEM UTILITIES TO ASSIST IN FAULT MANAGEMENT OF THE SYSTEM, PARTICULARLY RECOVERY FROM FAULTS IN COMMUNICATING PROCESSORS.
- O SELECTABLE FAULT TOLERANCE MODES FROM MINIMAL FAULT TOLERANCE TO TRIPLICATION AND VOTING.

APPROACH:

1. DEFINE SPECIFIC FEATURES AND REQUIREMENTS FOR THE VARIOUS FAULT TOLERANCE MODES, INCLUDING METHODS FOR ACHIEVING SOFTWARE FAULT TOLERANCE.
2. DEFINE REQUIREMENTS FOR THE REMAINDER OF THE OPERATING SYSTEM.
3. SPONSOR THE DESIGN, DEVELOPMENT AND TESTING OF THIS OPERATING SYSTEM.

EXPECTED RESULTS: SHOULD HAVE FAULT TOLERANT, DISTRIBUTED OPERATING SYSTEMS TO SUPPORT SINGLE OR MULTIPLE NODE COMPUTERS.

D. BRADY

Figure 6.

## DATA MANAGEMENT -- LANGUAGES

PROBLEM: THE STANDARDIZATION ON ADA WITHIN DOD AND NASA LEAVES ON-BOARD SOFTWARE DEVELOPERS WITH SEVERAL CONCERNS:

- O EFFICIENCY AND MATURITY OF THE COMPILER.
- O SHORT COMINGS OF THE LANGUAGE FOR REAL-TIME CONTROL APPLICATIONS.
- O SHORT COMINGS OF THE LANGUAGE FOR INTERPROCESS COMMUNICATION AND SYNCHRONIZATION.

OBJECTIVE: DEVELOP A HIGH-ORDER LANGUAGE (HOL) WHICH MORE EASILY MEETS THE REQUIREMENTS OF A REAL-TIME, INTERACTIVE DISTRIBUTED PROCESSING SYSTEM WITH A MATURE, EFFICIENT COMPILER BY THE YEAR 2000.

APPROACH:

1. FUND A STUDY TO TRADE THE VIABILITY OF EXTENDING ADA VERSUS STANDARDIZING ON SOME OTHER LANGUAGE WHICH IS MORE APPROPRIATE TO THIS APPLICATION.
2. IF ADA IS SELECTED, DEFINE A SET OF "STANDARD" EXTENSIONS TO THE LANGUAGE WHICH MEET OUR REQUIREMENTS.

EXPECTED RESULTS: AN ADA VARIATION WHICH WILL STANDARDIZE SOFTWARE DEVELOPMENT FOR s/c 2000 AND BEYOND.

D. BRADY

Figure 7.

## DATA MANAGEMENT -- FAULT TOLERANCE AND TESTING

### PROBLEMS/NEEDS:

- 0 SIMPLER FAULT DETECTION, ISOLATION, AND RECOVERY TECHNIQUES WHICH RETAIN ADHERENCE TO FUNDAMENTAL REQUIREMENTS (EG.  $P_F > 10^9$ /HR; DATA CONGRUENCY, CORRELATED, TRANSIENT, BRIZANTINE FAILURES, ETC.)
- 0 FLEXIBLE CONNECTIVITY AND CONTROL FOR DISTRIBUTED, TIME CRITICAL, INTERACTIVE PROCESSING
- 0 TRUSTWORTHY SOFTWARE VIA "FAULT" TOLERANCE; PERHAPS EVENTUALLY VIA ERROR-FREE CODE
- 0 INTEGRATION OF SECURITY (EG. MARKOV) FOR EVALUATION, VERIFICATION, & MODIFICATION
- 0 EXTENSION OF TECHNIQUES TO NON-GENERAL PURPOSE ARCHITECTURES (MASSIVE PARALLEL, DATA FLOW)
- 0 INCORPORATION OF NEW COMPONENT TECHNOLOGIES (VHSIC  $G_A A_S$ , ETC.)

### OBJECTIVE:

REDUCE RISK OF TECHNOLOGY SHORTFALL IF "COATTAILS" DON'T MATERIALIZE.

### APPROACH:

MONITOR AND, IF/WHERE NECESSARY, AUGMENT ONGOING PROGRAMS (EG SDI) VIA SELECTED DEVELOPMENT AND GROUND-BASED TEST BED DEMONSTRATIONS.

### EXPECTED RESULTS:

MATURE TECHNOLOGY BASE IN ALL AREAS ABOVE BY MID-LATE 90'S.

M. W. JOHNSTON 10/20/86

Figure 8.

## DATA SYSTEMS -- FIBER OPTIC NETWORKS

### PROBLEM:

500 MB FIBER OPTIC SPACECRAFT LOCAL AREA NETWORKS ARE NOT AVAILABLE TO SPACECRAFT SYSTEMS BECAUSE OF THE LACK OF SPACE QUALIFIED COMPONENTS.

### OBJECTIVE:

TO SPACE QUALIFY SEMICONDUCTOR LASER TRANSMITTERS, P-I-N RECEIVERS, ANALOG CONDITIONING AND STABILIZING CIRCUITRY, AND OPTICAL ELEMENTS NECESSARY TO IMPLEMENT SPACE QUALIFIED FIBER OPTIC LOCAL AREA NETWORKS (FOLAN) IN THE RANGE OF 300-500 MBT/SEC.

### APPROACH:

TO SPACE QUALIFY SINGLE MODE FIBER OPTIC CABLES, CONNECTORS.  
TO SPACE QUALIFY LASER TRANSMITTERS, P-I-N RECEIVERS.  
TO DEVELOP AND SPACE QUALIFY PACKETIZATION, AND PROTOCOL DECISION MAKING LOGIC.

### EXPECTED RESULTS:

COMPONENT TECHNOLOGY BASE TO ASSURE 300-500 MBPS LOW ERROR RATE FOLAN'S FOR SPACECRAFT.

Figure 9.



## DATA MANAGEMENT -- COMMUNICATION PROTOCOLS

PROBLEM: SUCCESSFUL INSERTION OF PACKET-SWITCHING TECHNOLOGY INTO SC-2000.

OBJECTIVE: REPLACE A MAJORITY OF SPECIAL CABLING IN SPACECRAFT WITH A PACKET-SWITCHED, SHARED COMMUNICATION MEDIUM (PROBABLY FIBER OPTICAL LOCAL-AREA-NETWORK BASED). MOST POINT-TO-POINT CABLES WOULD BE REPLACED BY A TAP INTO THE MEDIUM.

ISSUES: THIS TECHNOLOGY IS BEING DEVELOPED PIECEMEAL TODAY IN MANY LOCATIONS. HOWEVER, THE CONSTRAINTS FACED IN SC-2000 ARE NOT ADDRESSED BY EXISTING PROGRAMS. THE SC-2000 CONSTRAINTS/REQUIREMENTS INCLUDE:

- O REAL-TIME GUARANTEED RESPONSE
- O PRIORITY FOR CRITICAL COMMUNICATIONS
- O SUBSUMING (ALMOST) ALL POINT-POINT COMMUNICATIONS ON THE SPACECRAFT
- O RELIABLE COMMUNICATIONS (WELL BEYOND THE BIT ERROR RATE OF THE COMM. MEDIUM)
- O VERY HIGH BANDWIDTH
  - O SINGLE INSTRUMENTS 100-300 MBAUD
- O REPLACING TDM FOR MOST USAGES
- WHILE NO CONSTRAINT ABOVE IS PROHIBITIVE, THE SIMULTANEOUS SOLUTION OF ALL OF THEM IS BEYOND CURRENT TECHNOLOGY.

Figure 10a.

## DATA MANAGEMENT -- COMMUNICATION PROTOCOLS (CONTINUED)

- CURRENT LINK-LEVEL PROTOCOLS CANNOT HANDLE 100-300 MBAUD IF IMPLEMENTED IN SOFTWARE, AND ARE TOO COMPLEX TO IMPLEMENT IN HARDWARE. NEW PROTOCOL(S) ARE NEEDED.
- O THE ABOVE IS EVEN MORE TRUE OF TRANSPORT-LEVEL PROTOCOLS, WHICH ARE FAR TOO SLOW. A NEW PROTOCOL IS NEEDED HERE, TOO.

APPROACH: NASA SHOULD FUND A SC-2000 BRASSBOARD IMPLEMENTATION, SOLVING ALL THE ABOVE CONSTRAINTS SIMULTANEOUSLY IN A SYSTEM WHICH CAN BE THE TEST BED OR PROTOTYPE FOR THE PROTOCOLS, CHIPS, COMMUNICATION MEDIUM, OPERATING SYSTEM, FAULT DETECTION/RECOVERY, ETC.

### EXPECTED RESULT:

THE OUTPUT INCLUDES:

- O NEW PROTOCOLS
- O NEW COMM. CHIPS
- O WORKABLE ALGORITHMS AND STRATEGIES FOR FAULT TOLERANCE
- O WORKING OPERATING SYSTEM SOFTWARE

WITHOUT THE EARLY AVAILABILITY OF THIS TECHNOLOGY, SPECIAL INTERESTS WITH SPECIAL NEEDS WILL FORCE MULTIPLE NON-STANDARD INTERFACES INTO SC-2000, DUE TO THEIR OWN NEED FOR EARLY DESIGN FREEZES. THIS WILL MAKE THE NECESSARY COMMONALITY OF INTERFACE AND OF STANDARDIZATION IMPOSSIBLE.

Figure 10b.

## DATA MANAGEMENT -- SECURITY

**PROBLEM:** SC 2000 WILL HAVE TO SUPPORT A WIDE RANGE OF USERS, MANY OF WHICH WILL HAVE STRINGENT DATA SECURITY REQUIREMENTS. THESE REQUIREMENTS CANNOT BE MET BY PRESENT SYSTEMS.

**OBJECTIVE:** IDENTIFY SC 2000 SECURITY REQUIREMENTS IN DETAIL. PRODUCE A FORMAL SECURITY POLICY. INSURE THAT THE NEEDED SECURITY TECHNOLOGY IS AVAILABLE AND IS UTILIZED DURING THE SYSTEM DEFINITION PHASE.

**APPROACH:** NASA SHOULD BEGIN INTERACTIONS WITH THE NATIONAL SECURITY AGENCY AND THE NATIONAL COMPUTER SECURITY CENTER TO IDENTIFY NASA'S NEEDS IN SEVERAL AREAS:

- SOFTWARE SECURITY (ESP. COMM & OPERATING SYS.)
- COMMUNICATIONS SECURITY
- OPERATIONS AND DEVELOPMENT INTEGRITY ASSURANCE

**EXPECTED RESULTS:**

SECURITY ISSUE IS INCORPORATED DURING EARLY DEVELOPMENTS OF PROTOCOLS AND OPERATING SYSTEMS.

- IF NOT BEGUN NOW, SECURITY IS HARDER (OR IMPOSSIBLE) TO ADD LATER.
- SECURITY & FAULT TOLERANCE MAY BE COMPLEMENTARY (EG, CRYPTOGRAPHIC CHECKSUMS MIGHT AUGMENT OR REPLACE OTHER ERROR DETECTION CODES, WITH ADDED VALUE FROM RESULTING INTEGRITY CHECKS).

Figure 11.

## DATA MANAGEMENT -- TECHNOLOGY EVOLVABILITY BY TRANSPARENCY

1. **PROBLEM:** SUBSYSTEM HIERARCHICAL MODELS NEED TO BE EXERCISED IN A SYSTEM WIDE MODELLING TOOL. MODELLING RESULTS MUST BE VALIDATED IN A TEST BED PRIOR TO SUBSYSTEM INTERFACE/PROCESSOR-MEMORY-SOFTWARE PARTITIONING. HEURISTIC METHODS CURRENTLY IN USE CAUSE OVERDESIGN/UNDERDESIGN PROBLEMS AT SUBSYSTEM INTEGRATION. SYSTEMS MUST BE COMPLETELY REDESIGNED TO ACCOMMODATE TECHNOLOGY UPGRADES.
2. **OBJECTIVE:** SIGNIFICANT ARCHITECTURAL MODELLING TOOLS AND METHODOLOGY NEED DEVELOPMENT. PARTICULAR MODELS NEED TO BE DEVELOPED FOR PROCESSOR, STORAGE AND SOFTWARE. TEST BED DEVELOPMENTS MUST BE INITIATED TO MEASURE MODEL PARAMETERS AND VALIDATE END TO END MODELS.
3. **APPROACH:**
  - SELECTION OF METHODOLOGIES/HIERARCHICAL TOOLS
  - DEVELOP TOOL - MODEL ELEMENTS
  - ACQUIRE TEST BED ELEMENTS
  - INTEGRATE WITH OTHER SUBSYSTEMS & SUBSYSTEM MODELS
  - ITERATE SYSTEM CONFIGURATIONS/TOPOLOGIES TO GIVE VALIDATED DESIGNS
4. **EXPECTED RESULTS:**
  - FIRM PLANNING SYSTEM/SUBSYSTEM INTERFACE DEFINITIONS
  - SPECIFICATIONS FOR SUBSYSTEM DEVELOPMENTS
  - SYSTEM DESIGN MODELLED AND VALIDATED

Figure 12.